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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. EL 734727896 US

INVENTOR(S)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
Michelle D.	Simkulet	Cohoes, NY

Additional inventors are being named on the 1 *separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

: Integrated panoramic and forward optical system for omnidirectional signal processing

Direct all correspondence to: **CORRESPONDENCE ADDRESS**

☐ Customer Number:

OR

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ENCLOSED APPLICATION PARTS *(check all that apply)*

☑ Specification *Number of Pages* 9

☑ Drawing(s) *Number of Sheets* 5

☐ Application Data Sheet. See 37 CFR 1.76

☐ CD(s), Number

☑ Other (specify) assignment record.

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT

☑ Applicant claims small entity status. See 37 CFR 1.27.

☑ A check or money order is enclosed to cover the filing fees. #8817

☐ The Director is herby authorized to charge filing fees or credit any overpayment to Deposit Account Number:

☐ Payment by credit card. Form PTO-2038 is attached.

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☐ No.

☑ Yes, the name of the U.S. Government agency and the Government contract number are: US Navy N00014-03-M-0190

Respectfully submitted,

SIGNATURE Michelle D. Simkulet

Date February 6, 2004

TYPED or PRINTED NAME Michelle D. Simkulet

REGISTRATION NO. 43123
(if appropriate)

Docket Number: PP012004

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PROVISIONAL APPLICATION COVER SHEET
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Docket Number PP012004

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Jason E.	Smith	Latham, NY

Number 1 of 1

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IN THE UNITED STATES PATENT OFFICE

Mail Stop Provisional Application
Commissioner for Patents
PO Box 1450
Alexandria, VA 22313-1450

Dear Sir:

Transmitted herewith for filing is a **provisional patent application** of inventors:
Michelle Simkulet
Jason Smith
Jiayin Ma

For: Integrated Panoramic and Forward Optical System for Omnidirectional Signal Processing

Included in this mailing are the following items:

(x) Provisional patent application cover sheet

(x) Specification (9 pages)

(x) Drawings (5 sheets)

(x) Provisional application filing fee of $80 (check # 8817)

(x) Assignments of the invention to InterScience, Inc., with recordation sheet and recordation fee of $40 (check # 8817)

Sincerely,
Michelle Simkulet
Michelle Simkulet
Registration # 43123

CERTIFICATION OF EXPRESS MAIL UNDER 37 CFR 1.10

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Date of Deposit: February 6, 2004

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Michelle Simkulet
(name of person mailing)

Michelle Simkulet
(signature of person mailing)

Title: Integrated panoramic and forward optical system for omnidirectional signal processing

Inventors: Michelle Simkulet, Jiayin Ma, Jason Smith

Field of the Invention:

This invention relates to the field of omnidirectional optical systems. The optical system is comprised of two paths, panoramic and forward, seamlessly integrated on a single plane. The total field of view is comprised of the forward field of view and the panoramic field of view.

Background of the Invention:

There are many existing patents for optical systems that provide omnidirectional imaging. We believe we have some unique characteristics that are not covered in any existing patent and that provide a unique new capability to imaging systems and omnidirectional optical components in general. Jeffrey Charles has several U.S. patents on the subject including US patent 6,333,826 and US patent 6,449,103, BeHere Corporation has several US patents including US 6,392,687, US 6,424,377 and US 6,480,229, and Remote Reality has US patent 6,611,282.

The patents by Jeffrey Charles focus solely on the panoramic field of view, and efforts to maximize that field of view for near field applications. The Charles' patents include a frontal exclusion zone of about 60 degrees that can be tapered approaching the far field by the use of a torroidal-shaped reflector. Although this exclusion zone eventually disappears as a point where the boundaries of the panoramic field meet, there is no account in the patent for the overlapping area past the point of convergence in the processing or interpretation of the image. The minor disclosure of including forward optics to image the frontal exclusion zone makes no mention of details of how to match the magnification or the relative F/# of the integrated images as well as a means of interpreting or processing the overlapping images. The mere inclusion of forward viewing lenses does not automatically lend itself to an easily interpretable image. The focus of the optical system is near field prior to the overlap. Although there is provision to include the forward viewing optics to image the frontal exclusion zone, there will only be one point (or one radial distance) in which the frontal zone and the panoramic zone exist with either no gap or no overlap.

The BeHere technology also concentrates on the panoramic field of view and only makes provisions to extend the panoramic view as far forward as possible by changing the shape of the reflector. By placing a dimple in the apex of the parabolic reflector, imaging beyond the secondary reflector is achieved in the far field. These inventions provide no means for forward imaging in the near field.

The Remote Reality invention is a super wide-angle panoramic imaging apparatus that claims up to a 260° vertical field of view using a two reflector configuration. The invention includes an undefined blind spot along the optical axis. The invention claims a single view point while also having a substantially flat and stigmatic image plane.

Below are some summarizing details of each of the patents referenced above.

US 6,333,826 Jeffrey R. Charles
Omniramic Optical System Having Central Coverage Means Which Is Associated With a Camera, Projector or Similar Article

- single and two reflector embodiments
- two reflector embodiment produces frontal exclusion zone ~ 60 degrees
- produces annular image
- minimization of frontal exclusion zone using torroidal shape primary reflector
- achieves far field imaging with triangular shape frontal exclusion zone, beyond point, overlap in annular image
- discloses in specification only (column 26, line 57 - column 27, line 9) use of supplemental lenses in front of secondary mirror transparent area to image area greater than or equal to frontal exclusion zone, produces concentric images
- overlapping images to produce 3D info
- FOCUS: maximization of annular image boundaries, minimization of frontal exclusion zone, far field imaging, overlap of zones to produce 3-D image information

US 6,449,103 Jeffrey R. Charles
Solid Catadioptric Omnidirectional Optical System Having Central Coverage Means Which is Associated with a Camera, Projector, Medical Instrument or Similar Article

- solid optical substrate with primary and secondary internal reflectors and outer surface being convex refracting surface
- combination of primary reflector shape and outer refracting surface allows for imaging a point a finite distance in front of said optical system - thereby allowing for far field imaging only - but also subject to image overlapping beyond that finite point
- purpose of the convex refracting surface, which would be extremely difficult or even impossible to manufacture, is to extend the panoramic field of view boundaries.
- Claims 31-36 deal with solid optical substrate with primary and secondary internal reflectors in which secondary reflector has a transparent central zone with a concave surface or lenses to image central exclusion zone.

US 6,392,687 BeHere Corp.
Method and Apparatus for Implementing a Panoptic Camera System

- Two reflector design
- Main reflector consists of a paraboloid shape with a dimple on the apex such that the main reflector can capture light from behind a second reflector
- Details two cameras together to see an entire sphere and a stereo vision panoptic camera
- Similar to Charles' patent, still leaves a zone just beyond secondary reflector which is not viewable

US 6,424,377 BeHere Corp.
Panoramic Camera

- Single reflector design - mirror is parabolic cone shape
- Includes imaging camera, astigmatism correction lens, field flattening lens and objective lens

- Multiple sensors on same plane in mosaic pattern to achieve desired resolution
- Alternative embodiment 2 reflector design - camera housed within parabolic mirror (ONLY CONFIGURATION CLAIMED)
- Alternative embodiment single and 2 reflector designs whereas the parabolic reflector is the inside surface of a curved block of transparent material with refractive properties
- annular image presentation techniques including conversion to rectangular coordinates
- claims apparatus for capturing panoramic images
- claims apparatus with parabolic first reflector and light capture linearly proportional to angle of incidence on mirror

US 6,480,229 BeHere Corporation
Panoramic Camera

- single reflector convex mirror incorporating a beamsplitter to send annular image to two different electronic image capture devices (ONLY CONFIGURATION CLAIMED)
- Alternative embodiment 2 reflector design - camera housed within parabolic mirror Alternative embodiment single and 2 reflector designs whereas the parabolic reflector is the inside surface of a curved block of transparent material with refractive properties
- annular image presentation techniques including conversion to rectangular coordinates

US 6,611,282 Remote Reality
Super Wide-Angle Panoramic Imaging Apparatus

- two reflector configuration, primary reflector is a hyperboloid and secondary reflector is concave
- achieves up to a 260° vertical field of view which includes an undefined blind spot along the optical axis immediately behind the secondary reflector
- claims image is free of field curvature effects and astigmatic effects
- secondary reflector is an ellipsoidal or spherical mirror
- alternative embodiment includes reflective elements housed in solid optical block
- image mapable into Cartesian coordinate system

Summary of the Invention:

The objective of the present invention is to provide an omnidirectional optical system comprising an integrated panoramic / forward view imaging system that provides a coplanar omnidirectional image to a means of image display and/or recording. The present invention is comprised of a two optical path system that is combined on a single image plane. The present invention achieves matched magnification between the forward and panoramic images, relatively seamless boundaries with no overlap or blindspot, and a total field of view approximating 270 degrees azimuthally (vertically) about the entire 360-degree periphery. The invention can be utilized for surveillance applications as a pole mounted or ground mounted system or implemented in a stand-alone unit. The optical system can be miniaturized for endoscope and borescope implementation or alternatively enlarged for pipe inspection or other large-scale inspection implementations. An alternative non-imaging embodiment of the present

invention can be applied to optical free space communication as an omnidirectional optical antenna.

Brief Description of the Drawings:

Figure 1 is a two dimensional schematic of the optical system of the present invention.

Figure 2 is a two dimensional schematic showing the ray trace of the panoramic component of the optical system.

Figure 3 is a cross-sectional depiction of the fields of view attainable with the present invention.

Figure 4 is a representation of the image on the image plane.

Figure 5 is a two-dimensional schematic of an alternative embodiment of the present invention as an afocal optical system for non-imaging applications.

Figure 6 is a two-dimensional schematic of an alternative embodiment of the present invention that comprises directional zooming capabilities.

Detailed Description:

Purpose and Applications

The present invention has been configured as a means of achieving the widest field of view possible, including rear-viewing capabilities while minimizing distortion and without relying on panning and tilting mechanisms. Current wide field of view, non-moving, optical systems typically consist of fish eye optical systems. The distortion of fish eye optical systems is so great that it is not suitable for many imaging applications. The distortion is created by the non-uniform refraction of the light rays across the field of view. The boundaries of the field of view typically appear much more distorted than the central area of the field of view since the geometry of the optical system is meant to maximize the field of view. Advances in alternative panoramic imaging optical systems presents a means of imaging the periphery, but typically not the entire hemisphere in front of the imager. Single and dual reflector optical systems exist that provide peripheral imaging, but lack forward imaging. Pan and tilt optical systems provide the means to cover the same field of view, but require mechanical motion and do not present the entire field of view in a single instance on the image plane. For many applications the lack of constant viewing of the entire field of view or the requirement of mechanical motion is unacceptable. The present invention has applications that include but are not limited to surveillance, safety monitoring, industrial inspection, and medical endoscopy.

Optical System

The present invention is initially described with reference to Figures 1 and 2. Figure 1 shows the layout of the omnidirectional optical system **100** and Figure 2 shows the light path through the panoramic component of the optical system **100**. The omnidirectional optical system **100** is comprised of a primary reflector **102**, a secondary reflector **104**, a forward imaging lens group **106**, a focusing lens group **108**, an image plane **110**, and an optical axis **112**. The fields of view imaged by the omnidirectional optical system **100**

are detailed in Figure 3. The total field of view of the omnidirectional optical system **100** comprises a forward field of view **318** seamlessly bounded by a panoramic field of view **320** that can include a significant back angle field of view **322**.

In the preferred embodiment, the primary reflector **102** has a spherical geometry, with a hole through the central apex centered on the optical axis **112**. The proportion of the hole diameter to the reflective spherical surface is approximately 1:4.2. The radius of curvature of the primary reflector **102** in this embodiment is 20.102 mm. The spherical geometry of the primary reflector **102** was incorporated primarily for ease of manufacturing and low cost production. More complex geometries, such as a parabolic geometry, that are more difficult to manufacture, can be incorporated as an alternative. An alternative embodiment of the present invention comprise a primary reflector **102** with alternative convex geometries, but still include the hole along the optical axis **112**. In this alternative embodiment, the primary reflector **102** is a convex hyperbolic or convex parabolic reflector capable of forming a central panoramic catadioptric image. The minimal distortion caused by the focusing lens group **108** can be compensated with the correct bending power from the parabolic or hyperbolic primary reflector **102.** This alternative embodiment eliminates the minimal distortion aberration that exists using the spherical geometry for the primary reflector **102.**

In the preferred embodiment, the secondary reflector **104** has a flat or planar geometry, with a hole centered on the optical axis **112**. The secondary reflector **104** is placed in front of the primary reflector **102** with respect to the image plane **110** and is centered along the optical axis **112**. The proportion of the hole diameter to the reflective surface diameter is approximately 1:2.86. The planar reflector geometry provided an easy means of manufacturing. Alternative geometries such as concave or convex can be employed to tailor the optical system to meet specific fields of view or resolution requirements. Alternative embodiments of the present invention comprise a secondary reflector **104** with alternative convex or concave geometries, but still include the hole along the optical axis **112**.

Figure 2 specifically details the ray path through the panoramic component of the omnidirectional optical system **100**. Figure 2 details the rays at the boundary extremes of the panoramic field of view **320**. The forward boundary ray **216** traces the path from the periphery to the primary reflector **102,** to the secondary reflector **104**, and through the hole along the optical axis **112** in the primary reflector **102** to the focusing lens group **108** and the image plane **110**. Similarly, the rear boundary ray **214** traces the path from the periphery to the primary reflector **102,** to the secondary reflector **104**, and through the hole along the optical axis **112** in the primary reflector **102** to the focusing lens group **108** and the image plane **110**.

An integrated function of both the primary reflector **102** and secondary reflector **104** is to ensure the seamless boundary between the forward field of view **318** and the panoramic field of view **320**. The geometry and size of the primary and secondary reflectors **102,104** define the boundaries of the panoramic field of view **320** and is matched exactly to the boundary of the forward field of view **318** with no overlap and no gap. Additionally, the geometry of the primary and secondary reflectors **102,104** defines the F/# of the panoramic field of view **320**. The F/# can be interpreted as the brightness in the resultant image presented on the image plane **110** and the speed of the optical system. By matching the F/# of the panoramic-only optical system (primary reflector **102** plus the secondary reflector **104**) with the F/# of the forward-only optical system

(forward imaging lens group **106**), the brightness appears consistent over the entire image on the image plane **110**.

The forward imaging lens group **106** is designed to collect the forward field of view **318** and transfer it through the focusing lens group **108** to the image plane **110**. The forward imaging lens group **106** defines the forward field of view **318** boundaries and also defines the F/# of the forward field of view **318**. In the preferred embodiment of the present invention the forward field of view **318** spans approximately 80 degrees, +/- 40 degrees about the optical axis **112**. The forward imaging lens group **106** is placed directly behind the secondary reflector **104** with respect to the image plane **110** and it is centered on the optical axis **112**. In the preferred embodiment the lens elements in the forward imaging lens group **106** are spherical optical components fabricated of conventional optical materials such as BK7. The use of spherical optics and conventional materials lends to lower fabrication costs and cost effective system implementation.

The focusing lens group **108** is centered along the optical axis **112** and is placed in between the primary reflector **102** and the image plane **110**. The focusing lens group **108** collects the panoramic field of view **320** from the secondary reflector **104** and the forward field of view **318** from the forward imaging lens group **106**. It is the function of the focusing lens group **108** to focus the two independent optical paths from the panoramic field of view **320** and the forward field of view **318** onto a single image plane **110** and to control the image aberrations on this coplanar image. In the preferred embodiment of the present invention the primary reflector **102** is not solid and houses a portion of the focusing lens group **108** in the concave underside of its reflective surface. In the preferred embodiment the lens elements in the focusing lens group **108** are spherical optical components fabricated of conventional optical materials such as BK7. The use of spherical optics and conventional materials lends to lower fabrication costs and cost effective system implementation.

Image Plane

The forward field of view **318** and panoramic field of view **320** are integrated on a single image plane **110** to be presented as a single image. Figure 4 shows a schematic representation of the integrated image on the image plane **110** with the coplanar presentation of the forward field of view **318** and the panoramic field of view **320**. The coplanar single image presents many options for post processing not available to imaging systems that require panning and tilting to cover the same total field of view. Image processing techniques can be employed to remap the image plane **110** and present it to the user in a variety of formats. The image plane **110** is the focus of the coplanar integration of the forward field of view **318** and the panoramic field of view **320**. As shown in the figure the forward field of view **318** is concentrically presented with the panoramic field of view **320**. Although a boundary between the forward field of view **318** and the panoramic field of view **320** is designated on the schematic in Figure 3, it is there only to designate the difference between the image collected by the forward imaging lens group **106** and that collected by the primary reflector **102**. In actuality the omnidirectional optical system **100** produces a continuous image on the image plane **110** in which the boundary between the fields of view is not evident. The image plane **110** would typically be a visible or near-infrared imaging detector such as a CCD or CMOS camera or detector. The preferred embodiment of the present invention is optimized for integration with a 640 x 480 output file size on a 1/3" format sensor. Alternative embodiments of the present invention comprise the present omnidirectional

optical system **100** optimized for visible and near-IR sensors of various sizes and resolutions. The sensors can either be analog or digital and can range from the lowest resolution, approximately 160 x 120 pixels to the highest resolution, which at this time is greater than a 6 megapixel array.

Fields of View

The present invention provides an omnidirectional optical system **100** that provides a substantially hyper-hemispherical field of view that extends to a maximum 270 degrees azimuthally and 360 degrees peripherally as shown in Figure 3. This field of view is achieved by integrating a forward field of view **318** with a panoramic field of view **320** on a single image plane **110**. The forward and panoramic fields of view **318, 320** are non-overlapping and there is no blind spot or gap between them. The boundaries of the forward and panoramic fields of view **318, 320** are relatively parallel. The forward field of view **318** extends about 80 degrees total (+/- 40 degrees from the optical axis). The panoramic field of view **320** extends about 95 degrees (50 degrees above the horizon and 45 degrees below the horizon. The magnification is matched between the forward and panoramic fields of view **318, 320** and the F/# is matched between the forward and panoramic fields of view **318, 320**. The image formed on the image plane **110**, therefore, seems continuous, with no differences in brightness or size, and no distortion at the seamless boundaries. The geometry of the primary reflector **102** and the secondary reflector **104** defines the extent of the panoramic field of view **320.** Similarly the optical design of the forward imaging lens group **106** defines the extent of the forward field of view **318**. The extent of each the forward field of view **318** and the panoramic field of view **320** can be tailored to meet the exact specifications of the application in which the omnidirectional optical system **100** is being used.

Size and Materials

The invention has been demonstrated at a diameter of approximately 40 mm and a height of 62.5 mm for a omnidirectional optical system **100** optimized for a visible light imager. The invention can be scaled in diameter to accommodate different application requirements. It has been scaled to a diameter of 2.7 mm for endoscope / borescope applications. The exact specification of materials is application dependent. However, the preferred embodiment comprises a primary reflector **102** that is BK7 glass with a protected aluminum coating, a secondary reflector **104** made of polished aluminum, and all optical elements in the forward imaging lens group **106** and the focusing lens group **108** made of standard glass with an antireflection coating deposited on them.

Alternative Embodiments

Aside from the alternative embodiments listed above relating to individual component specification and application customization an additional embodiment is listed below. One alternative embodiment of the present invention comprises the omnidirectional optical system **100** optimized for integration with an infrared imaging sensor for thermal or far-infrared imaging, such as but not limited to an uncooled microbolometer or a focal plane array. This detector would be inserted at the image plane **110** of the optical system **100**. The wavelength differences in the signal being transmitted and processed require different optical materials, which have different optical properties and a system optimized to the microbolometer size and resolution. At this time the highest resolution far infrared uncooled microbolometer is 320x240 pixels. Specifically, distinct changes in the optical materials are necessary to account for the infrared band of the electromagnetic spectrum. The primary reflector **102** and the secondary reflector **104**

will be coated in gold. This is the standard for IR reflective coatings and is widely available from optical manufacturers. The choice of materials for the optical elements in the forward imaging lens group **106** and the focusing lens group **108** include Zinc Selenide (ZnSe), Sodium Chloride (NaCl) and Cesium Bromide (CsBr).

An additional alternative embodiment of the present invention is implementation of the omnidirectional optical system in a non-imaging application for omnidirectional free space communication. This alternative embodiment in which the omnidirectional optical system **100** is used as an omnidirectional optical antenna is depicted in Figure 5.

The primary components of the omnidirectional optical system **100** remain the same in this alternative embodiment and comprise the primary reflector **102**, the secondary reflector **104**, the forward lens group **106** and the focusing lens group **108**. In this embodiment, the primary reflector **102** and the secondary reflector **104** are used as large area light collectors to feed light from the panoramic field of view **320** into the focusing lens group **108**. Second, the forward lens group **106** is used as a wide-angle objective to bend the light from the wide-angle forward field of view **318** into the focusing lens group **108**. Third, the focusing lens group **108** comprises a set of front positive lenses and a set of rear negative lenses.

In this alternative embodiment, the optical system will be converted to an afocal system. This modification will include only the focusing lens group **108**. The image plane **110** will be set at infinity, which is represented by the rays emanating from the focusing lens group **108** in Figure 5. The afocal magnification will be maintained at an optimized level, which will depend on the detector/transmitter size and the overall dimensions of the optical system.

In this alternative embodiment, a diffraction limited optical system design is required for this long-range optical communication antenna application, especially for high data rate communication systems. If the design is not diffraction limited, wavefront errors may overlap the adjacent optical signals and confuse the decision-making circuits when the data rate reaches a certain level. The optical system forms the transmit beam and any errors will degrade the beam quality. The diffraction limit of the design is associated with the Rayleigh quarter wave criterion. It means the system wavefront error must be controlled around 0.075 (λ/13.3) waves. Optimization on lens configuration for the forward lens group **106** and the focusing lens group **108** and glass materials selection.

In this alternative embodiment, the image plane / detector plane **110** must be distortion free for the optical antenna application. For an afocal optical system, the power distribution on the image plane **110** is expected to be constant across the total field of view, which comprises the forward field of view **318** plus the panoramic field of view **320**. Any distortion will alter the transmitter power distribution, and will saturate the detector or weaken the signal strength. As mentioned above, the distortion free omnidirectional optical design is achievable by using either a convex hyperbolic or a convex parabolic mirror as the primary reflector **102**.

A final alternative embodiment of the present invention is implementation of the omnidirectional optical system **100** with directional zooming. Due to the unique configuration of the omnidirectional optical system **100**, directional zooming in the panoramic field of view **320** can be achieved by tilting the primary reflector **102**, which is typically spherical or alternatively parabolic. This alternative embodiment is represented

in Figure 6. By tilting the primary reflector **102** in the direction of interest, it changes the area on the primary reflector **102** that the image rays strike and the total path length, thereby changing the size of the image on the image plane **110**. The forward field of view **318** would either move away from the center of the image plane **110** or completely out of view, depending on the degree of tilt of the primary reflector **102**. However, this would not be a factor in the imaging since the zoomed area is the area of interest. It is expected that this configuration can achieve at least a 5x zoom on the area of interest. Additionally, directional zooming can be achieved in the forward field of view **318** by moving at least one of the elements of the forward viewing lens group **106** along the optical axis **110**.

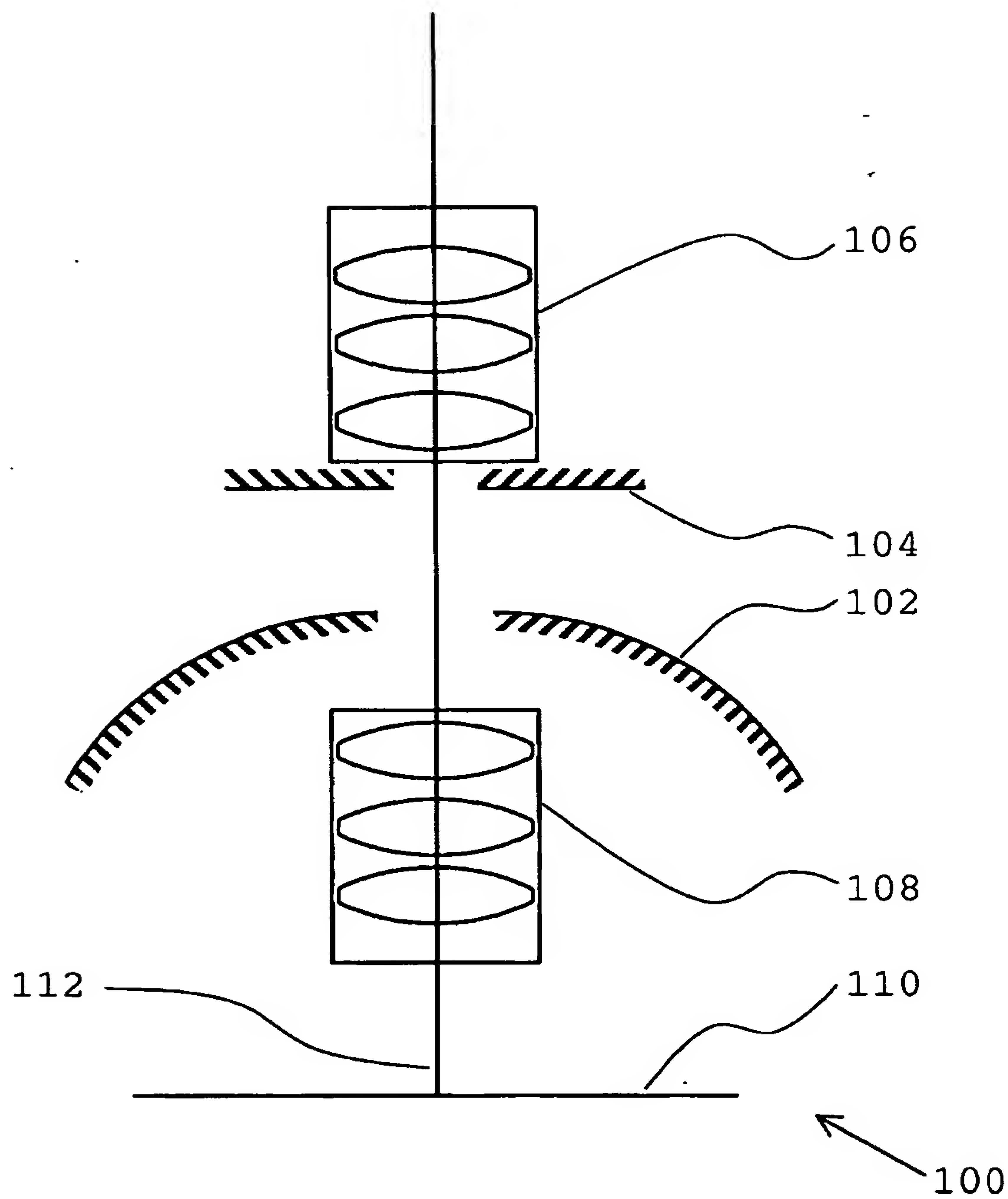

Figure 1

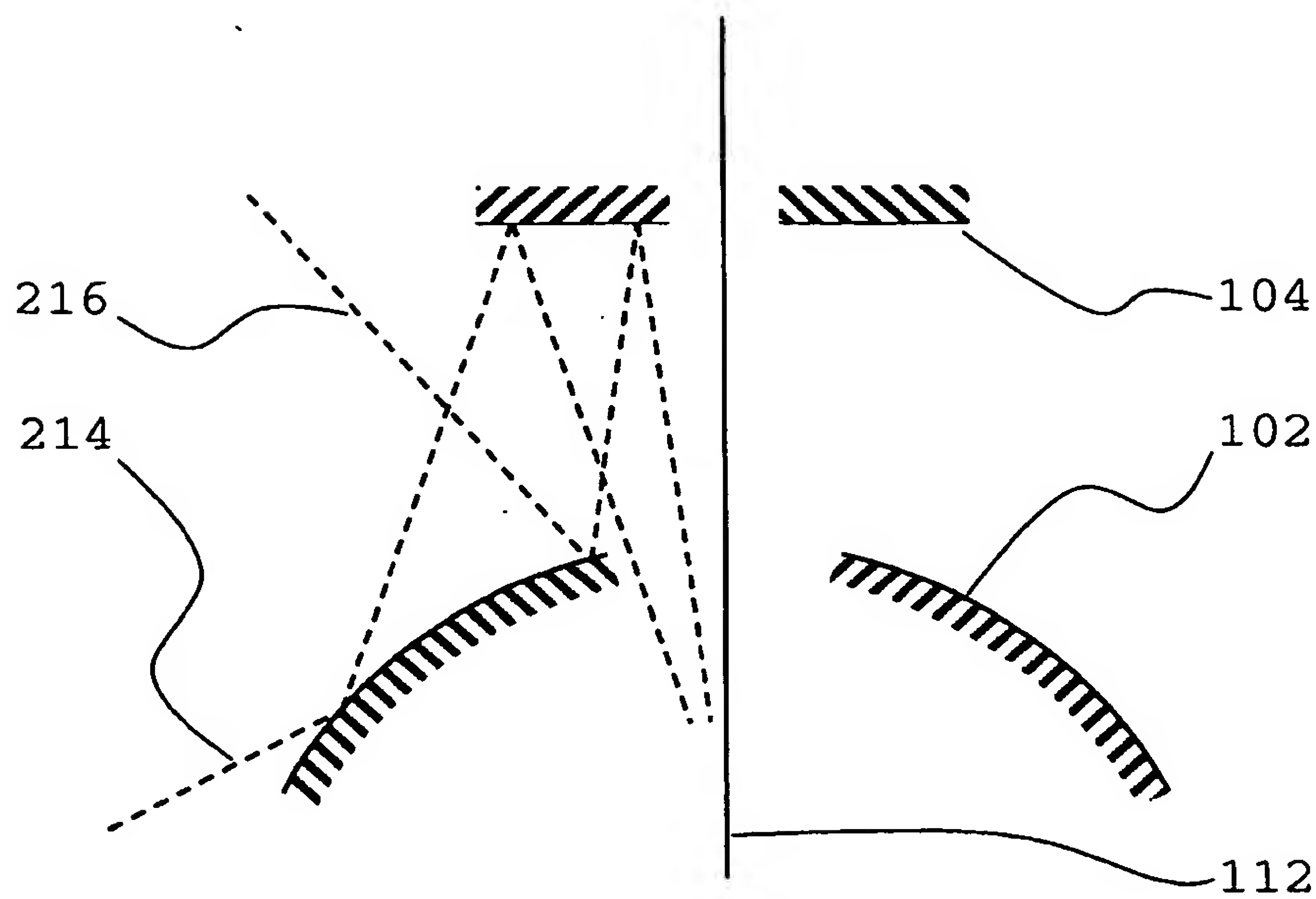

Figure 2

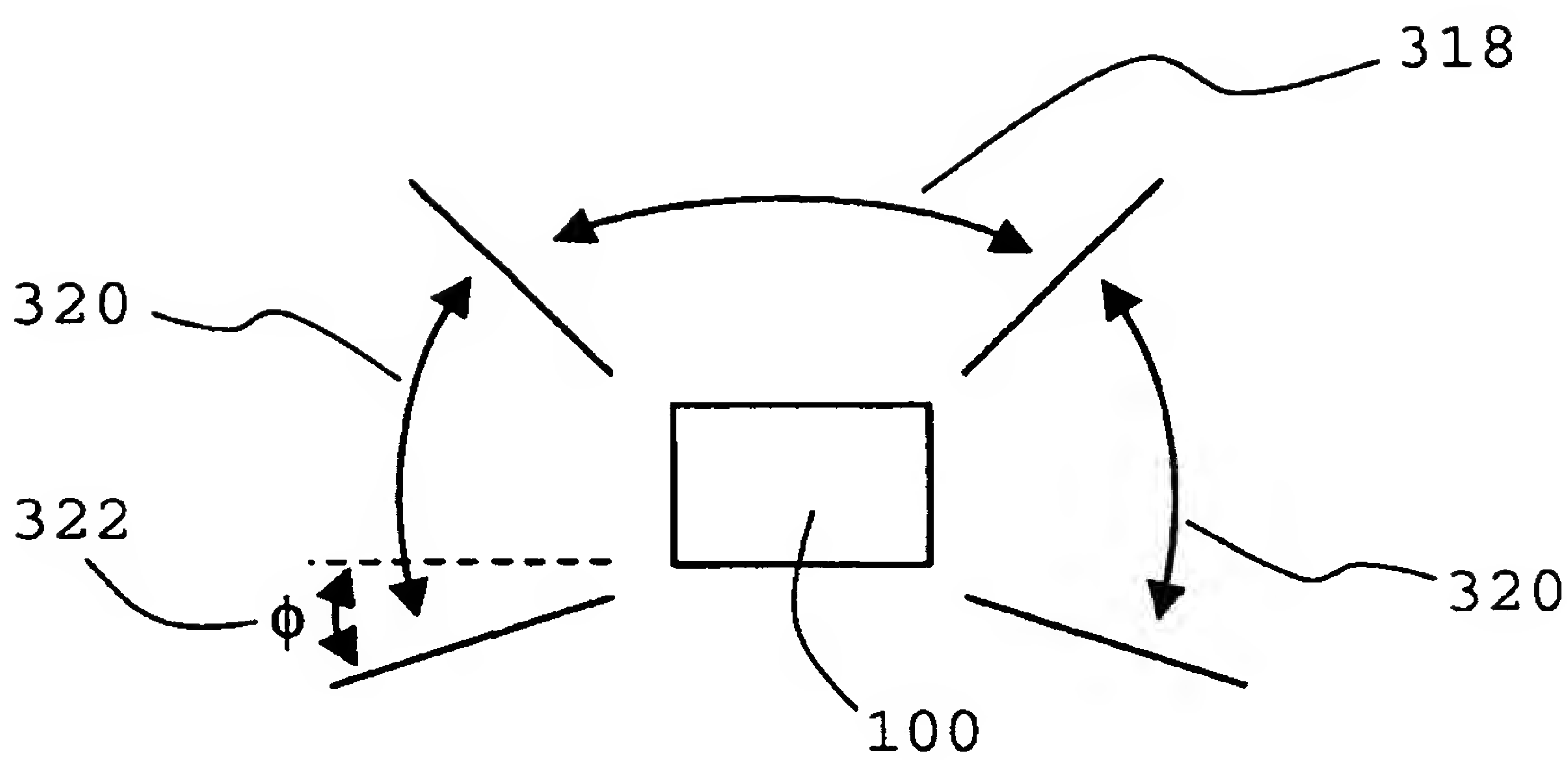

Figure 3

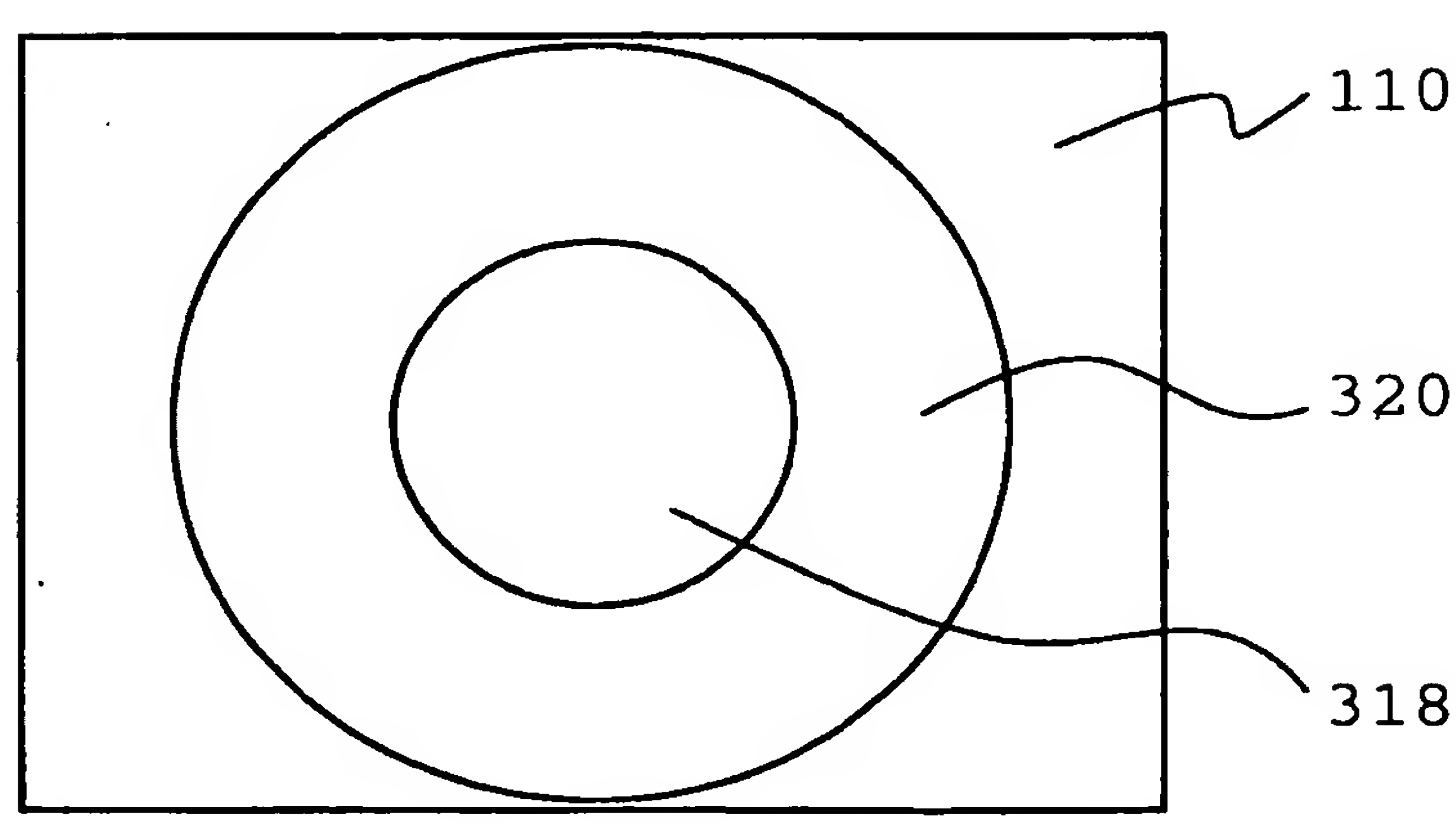

Figure 4

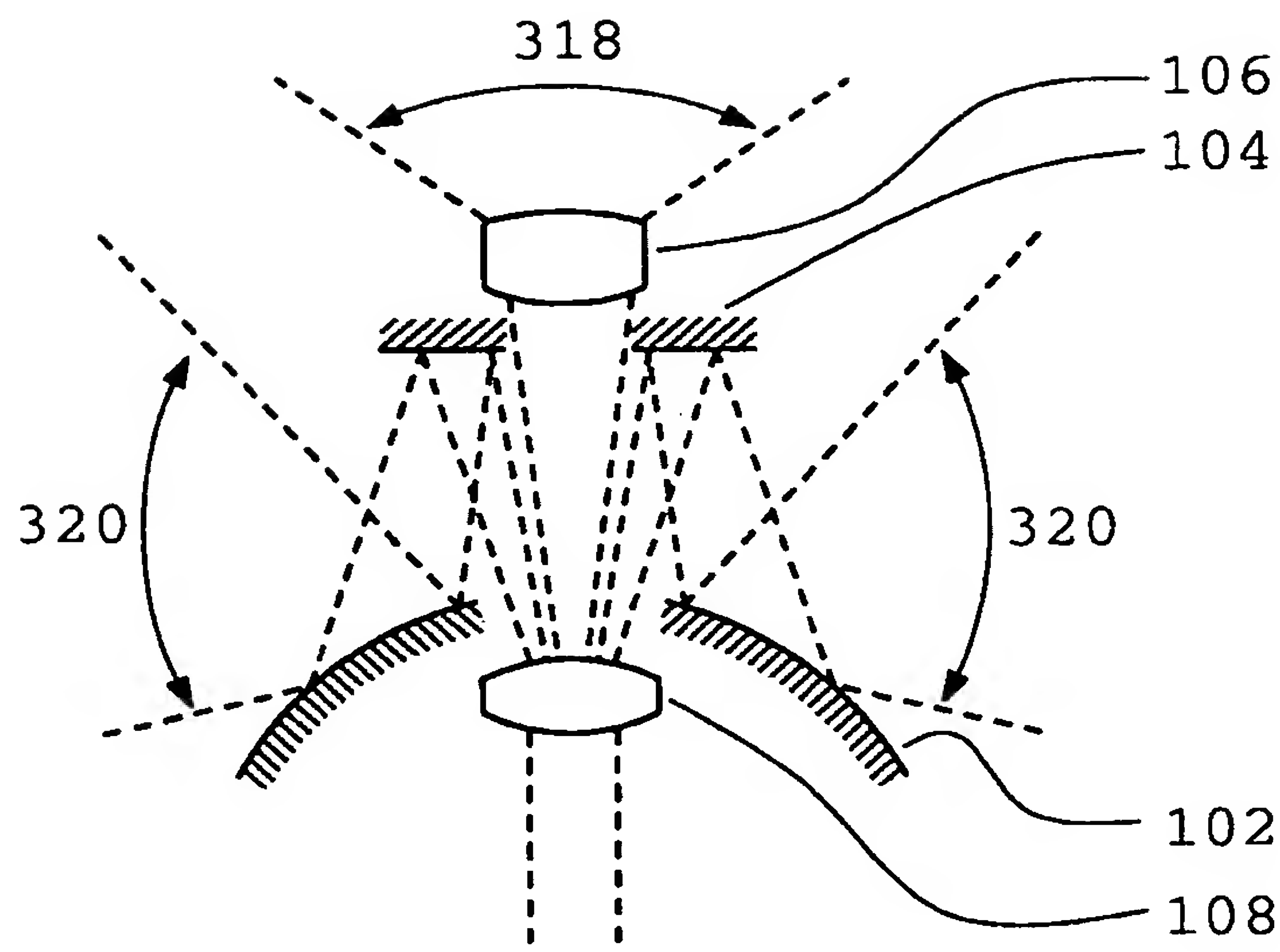

Figure 5

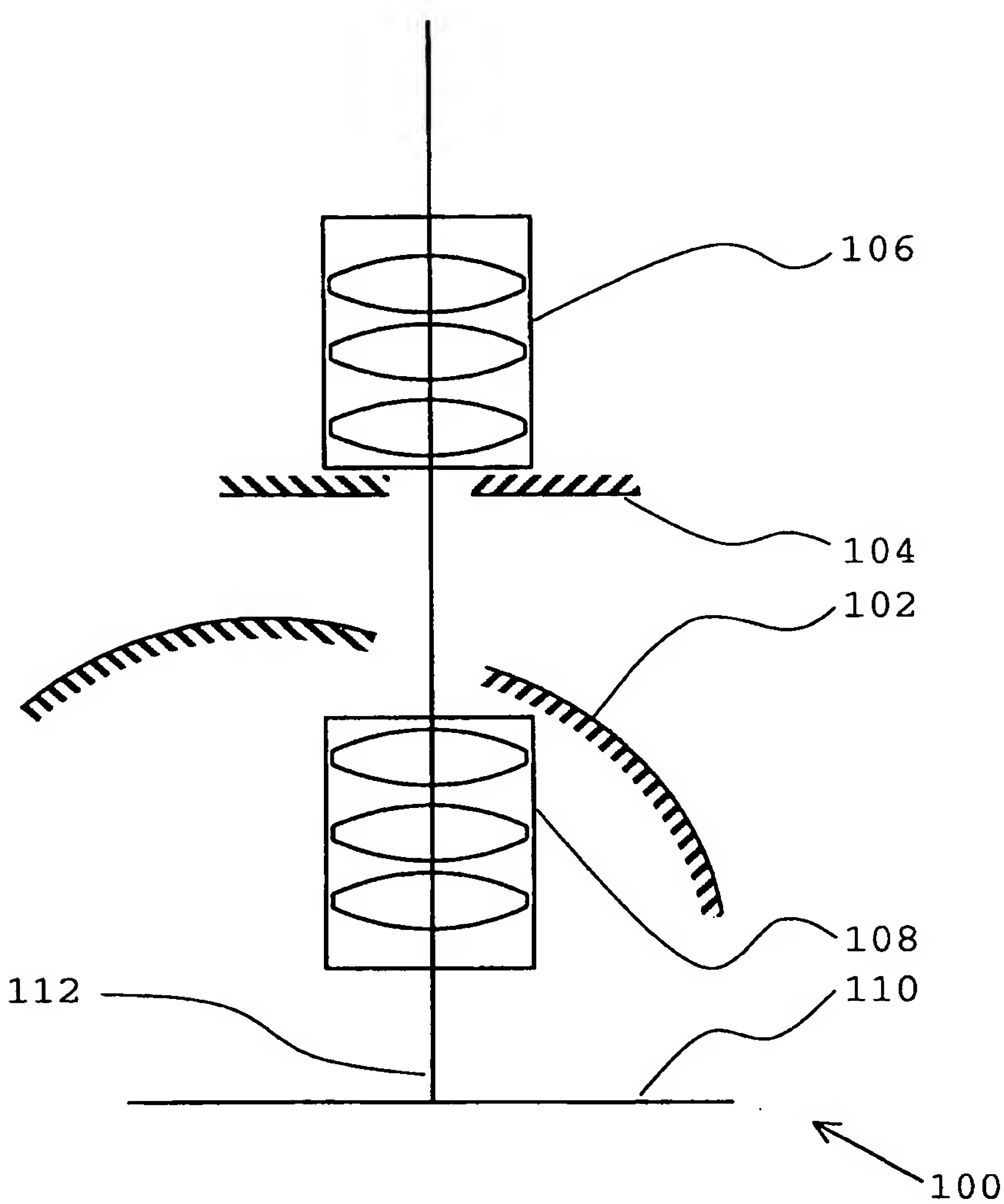

Figure 6